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HIGH FREQUENCY RESPONSE OF A RING-STIFFENED CYLINDER

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Defence Research Establishment Atlantic
Centre de Recherches pour la Défense Atlantique

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Approved by: R.W. Graham
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Abstract

Power Flow Finite Element Analysis (PFFEA) has been under development at Defence Research Establishment Atlantic (DREA) in support of the Ship Noise Project. PFFEA is an analysis method for predicting high frequency structural acoustic and vibration response. The method is based on a vibrational conductivity approach in which the flow of vibrational energy is modelled in a similar fashion to heat conduction with convective losses. This report discusses experiments performed with DREA's 3m ring-stiffened cylinder to assist in the validation of the PFFEA software for high frequency structural vibrations. The experiments involved excitation of the cylinder structure at relatively high frequencies using an electromagnetic/piezoelectric shaker located on either the cylinder shell or one of the ring-stiffeners. Both the input power and the response of the cylinder were measured with both harmonic and broadband excitation using an accelerometer. The power flow predictions for either input mobility (harmonic case) or input power (broadband case) did not correlate well with the measured data. The measured applied forces were used as input to predict the response of the cylinder to both harmonic and broadband excitation. Not unexpectedly, the predicted harmonic response did not compare favourably with the measured values in the frequency ranges dominated by modal behaviour; however, predictions were better at the higher frequencies where the response is not modal. The broadband predictions were more accurate for both locations of the shaker. The 1/3-octave band predictions were more accurate for the shaker on the shell and for both locations the results were better at higher frequencies.

Résumé

Le Centre de recherches pour la défense (Atlantique) (CRDA) travaille à la mise au point d'une méthode d'analyse par d'éléments finis du flux de puissance (PFFEA, ou Power Flow Finite Element Analysis) à l'appui du projet relatif au bruit de navire. La méthode d'analyse PFFEA est utilisée pour prédire la réponse acoustique et structurelle et la tenue aux vibrations aux hautes fréquences. La méthode est fondée sur la conductivité vibratoire, où le flux d'énergie de vibration est modelé sur la conduction thermique avec pertes par convection. Le présent rapport traite d'expériences réalisées à l'aide du cylindre à anneaux de renfort de 3 mètres du CRDA, lesquelles avaient pour but de valider l'utilisation du logiciel PFFEA dans le cas de vibrations structurelles hautes fréquences. Les expériences comportaient l'excitation de la structure du cylindre à des fréquences relativement élevées au moyen d'un vibreur électromagnétique / piézoélectrique placé soit sur la coquille du cylindre, soit sur l'un des anneaux de renfort. La puissance d'entrée et la réponse du cylindre ont été mesurées au moyen d'un accéléromètre en présence d'excitation harmonique et à large bande. Les prédictions de flux de puissance pour la mobilité (excitation harmonique) et pour la puissance (excitation à large bande) n'taient pas en corrélation avec les valeurs mesurées. Les forces appliquées mesurées étaient utilisées comme entrées pour prédire la réponse du cylindre en présence d'excitation harmonique et à large bande. Comme on pouvait s'y attendre, la réponse harmonique prédite ne se comparait pas favorablement aux valeurs mesurées dans les gammes de fréquences où dominent les comportements modaux. Cependant, les prédictions étaient meilleures aux fréquences plus élevées où la réponse n'est pas modale. Les prédictions concernant l'excitation à large bande étaient beaucoup plus précises pour les deux emplacements du vibreur. Les prédictions pour la bande d'octave 1/3 étaient plus précises pour les cas où le vibreur était sur la coquille et, dans le cas des deux emplacements, les résultats étaient meilleurs aux fréquences plus élevées.

DREA TM/98/221

High Frequency Response of a Ring-Stiffened Cylinder

by

L. E. Gilroy

Executive Summary

Introduction

Power Flow Finite Element Analysis (PFFEA) has been under development at Defence Research Establishment Atlantic (DREA) in support of the Ship Noise Project whose objective is to provide DND with the expertise and tools necessary to deal with issues related to underwater noise from naval vessels. PFFEA (also known as the Power Flow Finite Element Method, PFFEM) is an analysis method for predicting high frequency structural acoustic and vibration response. The method is based on a vibrational conductivity approach in which the flow of vibrational energy is modelled in a similar fashion to heat conduction with convective losses.

The PFFEM is not a mature technology and the bulk of the work at DREA has been focussed on the development of the methodology with initial work being directed towards the prediction of vibrational energy flow in beam and plate networks. As the method is developmental, relatively little work has been done to date to validate the computer codes produced against actual structural experiments. In light of this, DREA decided to perform a series of experiments involving test structures used in low frequency radiated noise experiments. This technical memorandum discusses experiments performed with DREA's 3m ring-stiffened cylinder to assist in the validation of the PFFEA software for high frequency structural vibrations.

Principal Results

The experiments involved excitation of the cylinder structure at relatively high frequencies (2 kHz to 16 kHz, in general) using a combination electromagnetic/piezoelectric shaker located on either the cylinder shell or one of the ring-stiffeners. Both the input mobility and the transfer mobility of the cylinder were measured with both harmonic and broadband excitation using an accelerometer.

The power flow predictions for either input mobility (harmonic case) or input power (broadband case) did not correlate well with the measured data. It was not clear whether this was due to inadequacies in the numerical method or the actual test measurements. The numerical method did not allow for the mass of the shaker and assumed either an infinite plate or an infinite single-stiffened plate. The measured data showed negative input power at some frequencies which may be a result of an instrumentation problem or, possibly, a result of radiated noise acting as a secondary source.

The measured applied forces were used as input to predict the response of the cylinder to both harmonic and broadband excitation. The results from these tests were much more encouraging. The predicted harmonic response did not compare favourably with the measured values, particularly in the frequency ranges dominated by modal behaviour. This behaviour

was not unexpected. Predictions were better at the higher frequencies where the response is not modal. The broadband predictions were more accurate for both locations of the shaker. The 1/3-octave band predictions were more accurate for the shaker on the shell and for both locations the results were better at higher frequencies (outside of the predominantly modal area).

Significance of Results

The results from this experiment show that, given the measured input force, the PFFEM can be used to accurately predict the high frequency response of the ring-stiffened cylinder subjected to broadband excitation. Due to its inherent inability to accurately model modal behaviour, the PFFEM cannot be used in frequency ranges were the modal density is relatively low. The PFFEM also appears to be reasonably accurate in its ability to model high frequency harmonic response. The experiments showed that the existing methodology appears to be inadequate in predicting either input mobility or input power or that the experimental procedure needs to be considerably refined to account for the discrepancies. The phenomenon involving the possibility of secondary load paths warrants further investigation to determine if this capability can be included in the software, as this particular class of problems are those likely to be of most interest.

Future Plans

Further testing to validate the PFFEM is required. DREA is currently planning trials involving the measurement of input power and structural response in a compartmented steel box structure. This will allow for validation of the plate and stiffener junction modelling capabilities of the PFFEM software.

Contents

1 Introduction

Power Flow Finite Element Analysis (PFFEA) has been under development at Defence Research Establishment Atlantic (DREA) in support of the Ship Noise Project whose objective is to provide DND with the expertise and tools necessary to deal with issues related to underwater noise from naval vessels. PFFEA (also known as the Power Flow Finite Element Method, PFFEM) is an analysis method for predicting high frequency structural acoustic and vibration response. The method is based on a vibrational conductivity approach in which the flow of vibrational energy is modelled in a similar fashion to heat conduction with convective losses.

The PFFEM is not a mature technology and the bulk of the work at DREA has been focussed on the development of the methodology with initial work being directed towards the prediction of vibrational energy flow in beam and plate networks [1, 2, 3, 4, 5, 6]. Recent work includes the development of methods for predicting the vibratory response in fluid-loaded structures and the resulting radiated noise. As the method is developmental, relatively little work has been done to date to validate the computer codes produced against actual structural experiments. A pilot study involving the examination of a simulated semi-infinite beam [7] is one such example. In light of this, DREA decided to perform a series of experiments involving test structures used in low frequency radiated noise experiments. These include DREA's 3m ring-stiffened cylinder [8, 9], a ship tank test model, and the Acoustic Calibration Barge [10].

This technical memorandum discusses experiments performed with the ring-stiffened cylinder to assist in the validation of the PFFEA software for high frequency structural vibrations. The memorandum will discuss briefly the background to the PFFEA method then describe the experimental procedure and equipment used. Comparisons will be made between the measured response of the cylinder and the predicted response based on the PFFEM.

2 Background

Power flow finite element analysis (PFFEA) is a new and potentially powerful method for vibroacoustic analysis of structures. It uses a vibrational conductivity modelling of structural components in which the flow of vibratory energy is treated in a way analogous to the flow of thermal energy in steady state. This comes about by applying time-averaged and local space- averaged expressions for energy density and power flow to a unit volume of a structural component. This results in a second-order conductivity equation governing the distribution of vibrational energy. The basic equations for PFFEA are obtained by spatial discretization of the differential equation. Energy in each vibration type (e.g. flexural, torsional, etc.) can be modelled separately with PFFEA, with coupling occurring at junctions of components.

The real advantage to PFFEA comes from the time and space averaging, which ensures that the predicted energy distributions will be smoothly varying across a structural component. This makes the method highly suitable for random or broadband excitation, in which local variations in the vibratory response tend to be smeared out. Such response profiles over broad frequency ranges cannot be computed with reasonably sized FE meshes, making PFFEA much more

efficient than FE analysis for higher frequency vibrations. A further advantage comes from its capability as a design tool. PFFEA not only predicts the vibrational energy distribution, but also maps out the flow of vibrational energy in the structure. With conductivity modelling, only the irreversible (i.e. non-reactive) power flow is mapped, enabling the visualization of dominant transmission paths. This may be a valuable aid in the design of a structural system, and may also lend insight to an appropriate vibration control strategy.

PFFEA is, in a sense, an interdisciplinary method. It utilizes many of the physical concepts already accepted in the realm of structural acoustics, while applying the equation solving power of the finite element method. PFFEA also enjoys some important advantages over the standard method in vibroacoustics: statistical energy analysis (SEA). This method treats entire structural components much like an element of volume in PFFEA. Only a single response value for each energy type can be computed for a component, as opposed to the response profiles generated by PFFEA. Moreover, SEA modelling can be very cumbersome in complex systems, as individual coupling elements must be supplied at every interface. Because PFFEA is FE based, the vibroacoustic model can be based directly on the geometry of an existing FE model. Also, the PFFEA equations are in the same form as for static FE analysis and can therefore be solved with standard analysis routines. Unlike SEA, PFFEA has the capability for modelling nonuniform distributions of damping material. This is important in modelling layers of viscoelastic material applied to structural members, a common technique for passive vibration control.

The development of PFFEA has progressed to a stage at which relatively complex structural models can now be evaluated. The PFFEA system consists of a PFFEA translator program which converts an FE model to a PFFE model and the field equation solver VASTF [11] which performs the PFFEA analysis. The system has been tested on a variety of structural models including frames, stiffened and unstiffened plates, and cylinders. Recent efforts have been directed toward the modelling of energy transmission through arbitrary junctions of components, so that now PFFEA can be conducted on most structural configurations involving nearly all types of one- and two-dimensional elements.

3 Experimental Procedures

3.1 Equipment

DREA's ring-stiffened right cylinder was constructed using a 9.5mm thick tube with a nominal diameter of 762mm (30in), with a weld seam running longitudinally along the entire length. Five circumferential stiffeners were welded into the tube (continuous welds) at equal intervals of 0.5m. These stiffeners had a square 38.1mm $\times$ 38.1mm cross-section. Threaded 9.5mm radial holes facing inwards were also provided at 45° intervals on every ring stiffener to allow for the attachment of various pieces of equipment [12].

Removable endcaps 76.2mm thick were constructed of nominal 3in plate and welded to the tube. The endcaps were of two pieces with a central 'hatch' roughly 600mm in diameter, which

was bolted to the remainder of the endcap and sealed with an O-ring. Ring bolts were welded to the endcaps at various positions to allow for handling of the cylinder and the endcaps. A photograph of the cylinder on its transport carriage is shown in Figure 1.

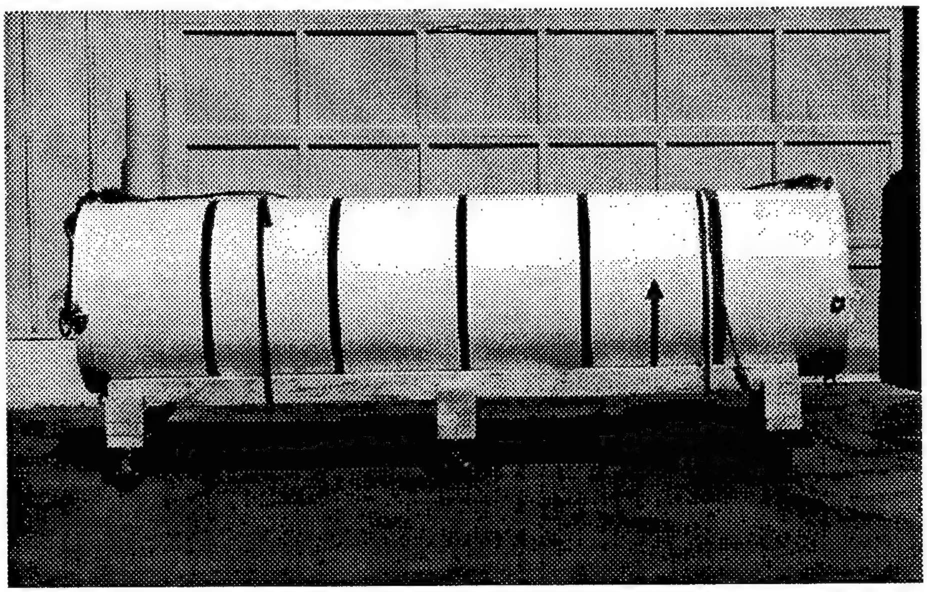

Figure 1: Test Cylinder

A Wilcoxon F4/F7 combination electromechanical/piezoelectric shaker was used to provide the loading on the cylinder. The F4/F7 shaker uses a single point mount system and includes an integral impedance head with sensitivities of 12.9 mV/g (acceleration) and 17.0 mV/N (force). The cylinder response was measured using B&K Model 4370P accelerometers attached to B&K Model 2635 charge amplifiers. The response was viewed using an HP35670A Signal Analyzer.

3.2 Measurements

The cylinder was suspended from a 3-tonne capacity crane using steel cable slings in a concrete well in the Heavy Engine Lab at DREA (such that the lower half of the cylinder was in the well). The bottom cap of the cylinder was removed to allow access for the shaker cables. This was done for convenience as the cylinder was constructed to allow for internal operation of a shaker and up to 48 accelerometers with the endcaps in place. The shaker was installed inside the cylinder and oriented to produce radial loads. Two source points were examined, one on the cylinder's centre stiffener and one midway between two stiffeners (see Figure 2).

For each of the two load points, several sets of measurements were made. The first test involved the measurement of the input mobility and input power as a function of frequency.

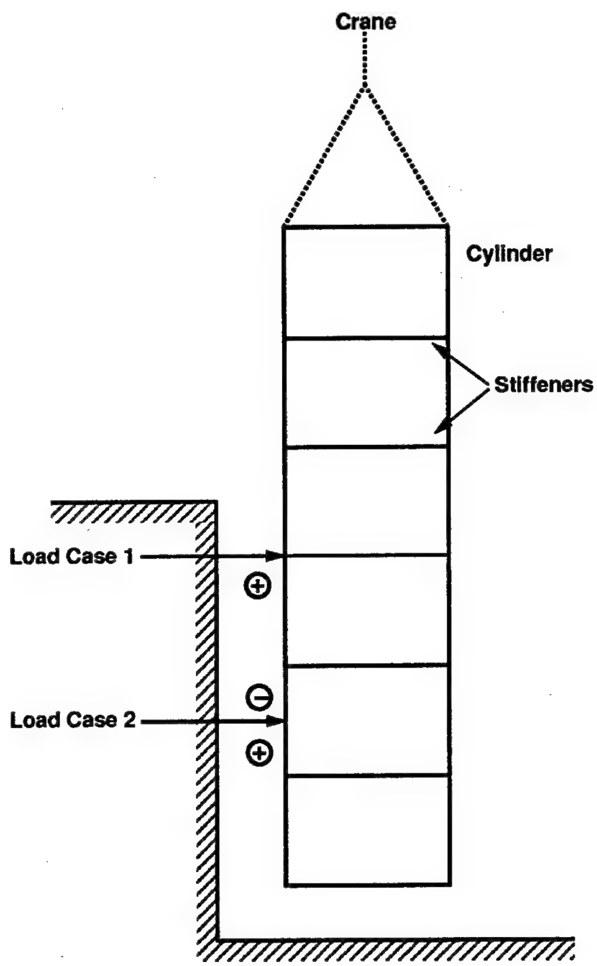

Figure 2: Schematic of Cylinder Experiment

Random noise excitation was used as input to the shaker generated using the HP signal analyzer. Upon completion of these tests, the response of the cylinder along a portion of its length was examined. For both load points, response to both harmonic and random noise excitation was measured. Selected frequencies were chosen for the harmonic excitation to cover a range of 500 Hz to about 10 kHz. This allowed for measurements from lower frequencies with medium modal density to high enough frequencies such that the structure exhibited no modal characteristics. With the shaker on the stiffener, the results using the selected frequencies were not acceptable as it appeared the choices were very close to resonant modes of the cylinder. Subsequently, the frequency range was shifted to span from 2 kHz to 16 kHz. To examine broadband excitation, the response of the cylinder to random noise excitation was recorded using both 1/3- and full-octave bands. The response was measured at 0.125m intervals (1/4-frame spacing) along the cylinder. With the shaker on the stiffener, measurements were made from the shaker location to the bottom of the cylinder. With the shaker on the plate, measurements were made at equal distances above and below the shaker location. The axial position sign convention is indicated in Figure 2. The measured input power for the 1/3- and full-octave band excitation was obtained from the cross-spectral density of the velocity and force signals, which was integrated over the whole band of frequencies [13].

4 Numerical Model

4.1 Input Power

The numerical model used to obtain the theoretical input power involved modelling the cylinder as either an infinite flat plate, in the case of excitation on the shell plating, or as an infinite plate with a single reinforcing stiffener, in the case of excitation on the stiffener. This involves two levels of approximation. The first is approximating a cylindrical shell as a flat plate. The other is approximating a finite system as an equivalent infinite system.

With regard to the former, the standard theories for cylindrical shells predict that above the so-called ring frequency the flexural motion of the shell becomes decoupled from the membrane action. This means flexural and in-plane modes propagate independently, i.e., just like a flat plate. The same idea holds for modelling rings as straight beams, except the frequency range will be a bit more restrictive since rings are usually thicker than shells. The ring frequency for the cylinder was determined to be 2.3kHz [4] which is at the bottom end of our measurement frequencies.

Modelling a finite system by its infinite equivalent is discussed in [14]. The idea is that when the driving point frequency response is plotted on a log scale, it is possible to plot a curve through the response that is equidistant from the resonant peaks and antiresonant troughs. In the limit of high frequency, the resonances and antiresonances converge toward this mean curve. This high frequency limit is conceptually the same as the moving the boundaries out to infinity while keeping the frequency constant. Therefore, the mean curve is just the driving point response of the equivalent infinite system. This holds for any type of structure, provided

one is looking at the driving point response. It does not hold true for transfer mobilities, which is why it is necessary to use PFFEA to get the response at locations other than the driving point.

For the harmonic case, theoretical mobilities were calculated for comparison with predicted values. For the broadband excitation of the cylinder shell and stiffener, the theoretical values for the input power were obtained using the measured band force and the predicted theoretical mobilities evaluated at the centre frequency of each band.

4.2 Response

Figure 3 shows the numerical model used to calculate the response of the cylinder. The endcaps were not incorporated in the model as they had been removed from the cylinder for the experiment. The element size was limited to one element between each stiffener longitudinally and eight elements circumferentially. Further refinement of the model was deemed unnecessary as, unless there is significant damping within a structural section, the power flow method predicts essentially constant energy density over that element. With the simple (relatively) structure modelled here, this was considered a reasonable assumption. For the response predictions, the measured input force (harmonic) or band force (broadband) was used as the input force to the numerical model. This was necessary due to the relatively poor predictions of input mobility or power as will be discussed in the following section.

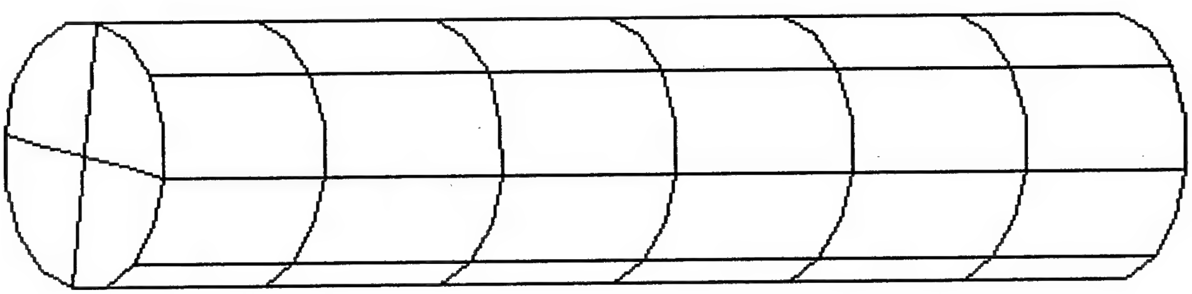

Figure 3: Numerical Model of Cylinder

5 Results

5.1 General

The following two sections compare the results of the experimental measurements with the values predicted using the PFFEA software. For the harmonic response and input, the vertical axis has units of mobility (velocity divided by input force). The octave band inputs are given as power while for the octave band responses, the vertical axis is given as 'Corrected RMS

Velocity'. For these plots, the RMS velocities were normalized to a 1 Newton(RMS) force so that comparisons could be made between various frequency bands (measured applied forces varied considerably with frequency). The horizontal axes use the position along the cylinder with each unit indicating one frame or 500mm.

5.2 Shaker on Stiffener

5.2.1 Input Power and Mobility

Input power predictions were made for both broadband and harmonic applied loads. Comparisons between the measured and theoretical input power are shown in Figure 4 for the harmonic case (mobility) and in Figure 5 for the broadband case (power). As can be seen in Figure 4, the predicted harmonic results are only reasonably accurate at the highest frequency of 10 kHz. The measured curves include four separate measurements of input mobility which show remarkable repeatability. Figure 5 shows that while the predicted input power was of the same order of magnitude as the measured (for both 1/3- and full-octave bands), the curves did not correlate well. The 1/3-octave and full-octave band curves did compare well with each other for both the measured and theoretical results.

For both the harmonic and broadband cases, the measured data show negative input power which is of some concern. This indicates that there is a net flow of power out of the cylinder at the force input point. The exact mechanism for this is not clear, but contributing factors may include a mismatch between the position of the shaker and the measuring accelerometer (they were on opposite sides of the cylinder shell) resulting in an apparent phase shift in the response, effects of the mass of the shaker (3.5 kg) which was not included in the theoretical model, and a secondary load path resulting from airborne noise. The latter may have been significant as certain excitation frequencies produced reasonably strong audio response which may have excited the cylinder from within and from without due to reflections off the walls in close proximity to the cylinder (within 1m on two sides). The poor prediction of input mobility resulted in measured input forces being used for the predictions of the response of the cylinder in the following section. While the first two factors may be accounted for in subsequent trials, the secondary acoustic load path may make input power predictions unreliable in general.

Another possible source of error is in the measurement method itself. The real part of the mobility is obtained by measuring the magnitude and phase of the mobility. As phase angles are not normally measured to the same accuracy as magnitudes, a large error may occur in the real part of the mobility even when the magnitude is measured correctly. The real part is particularly sensitive to phase angle errors for phase angles near 90°, which is typically the case for lightly-damped structures at non-resonant frequencies.

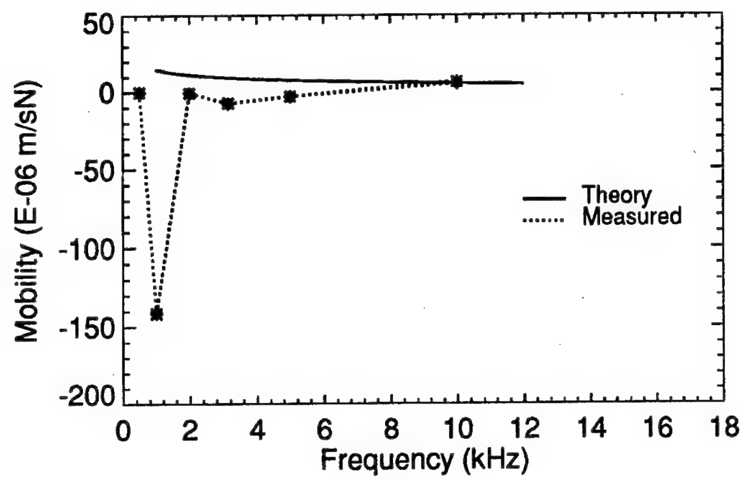

Figure 4: Harmonic Driving Point Mobility (Real Part)

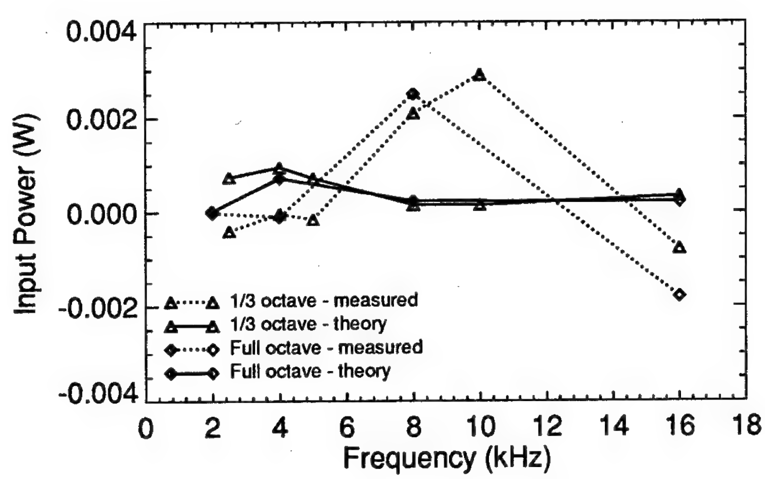

Figure 5: Broadband Input Power

5.2.2 Transfer Mobility

Given the relatively poor predictions of the input power and mobility, the measured input forces were used to predict the response of the cylinder as indicated above. As can be seen in Figures 6 to 11, the comparison between the predicted and measured mobility over the half-length of the cylinder improves with higher frequency. The prediction at 500 Hz is poor. The predictions from 1 kHz to 3.15 kHz are of the correct magnitude, but little better, while the predictions at 5 kHz and 10 kHz are more accurate. It should be noted that the excited cylinder exhibits predominantly modal behaviour up to about 6 kHz. Thus, power flow predictions would be most accurate above this frequency. Figures 12 to 18 show the results of the 1/3-octave band measurements. The agreement in most cases is again only of the same order of magnitude. The modal behaviour in the measured data is quite apparent in the low frequency bands (the stiffeners occur at the 1.0 and 2.0 points on the cylinder). The higher frequency bands do show a common trend between the measured and predicted results in descending velocity with position but, in general, the results are underpredicted. Figures 19 to 22 show the results for the full-octave band. Overall, the comparison between the predicted and measured response is better than that for the 1/3-octave bands, including the obviously modal measured response centred around 2 kHz (while still significantly low in this case). The three higher frequency full-octave band predictions are more accurate than all but the 16 kHz 1/3-octave band.

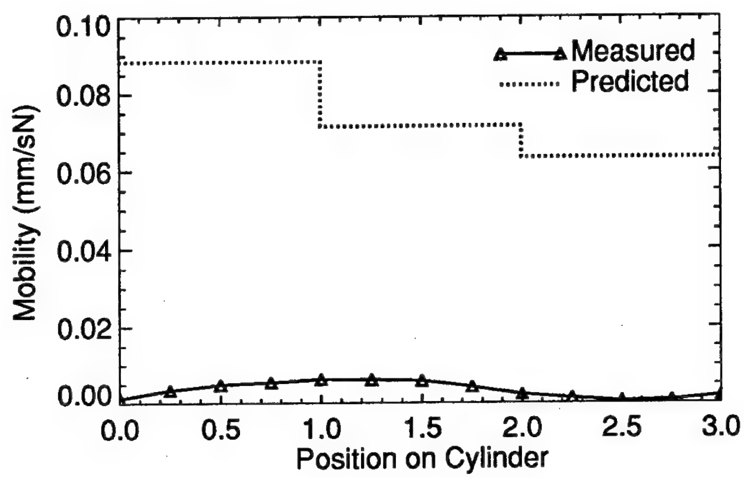

Figure 6: Harmonic Excitation - 500 Hz

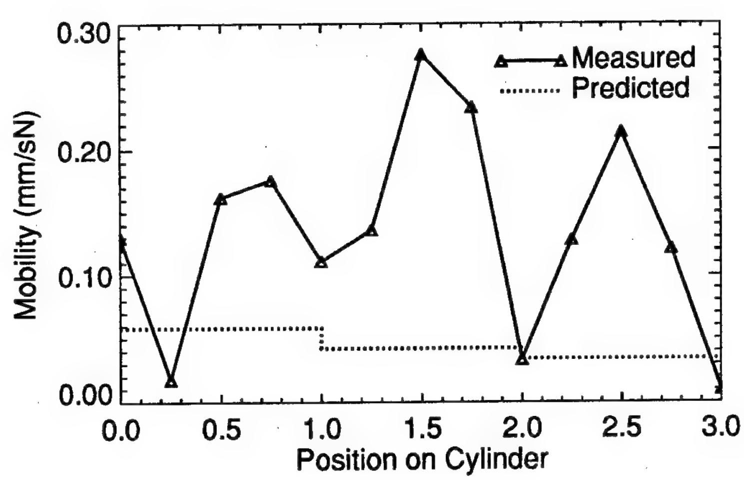

Figure 7: Harmonic Excitation - 1 kHz

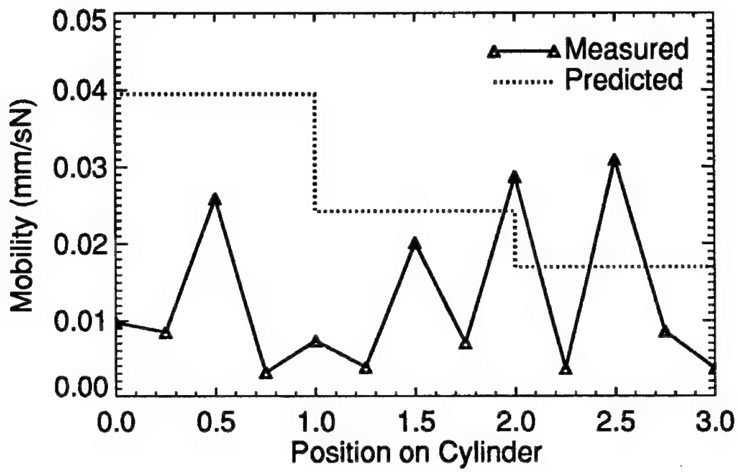

Figure 8: Harmonic Excitation - 2 kHz

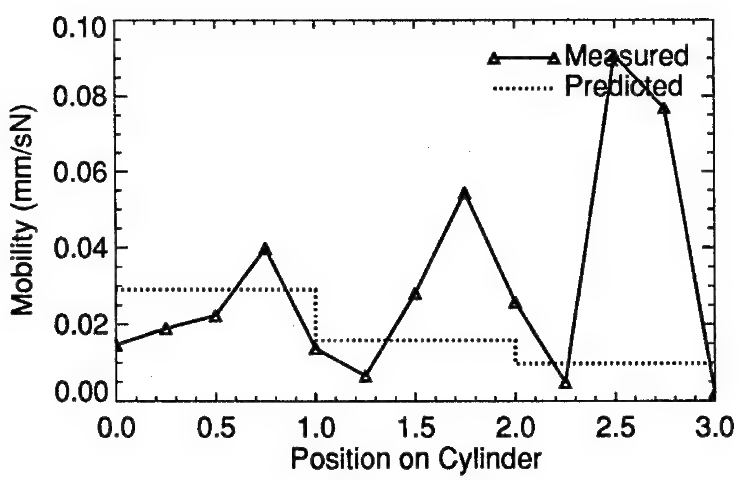

Figure 9: Harmonic Excitation - 3.15 kHz

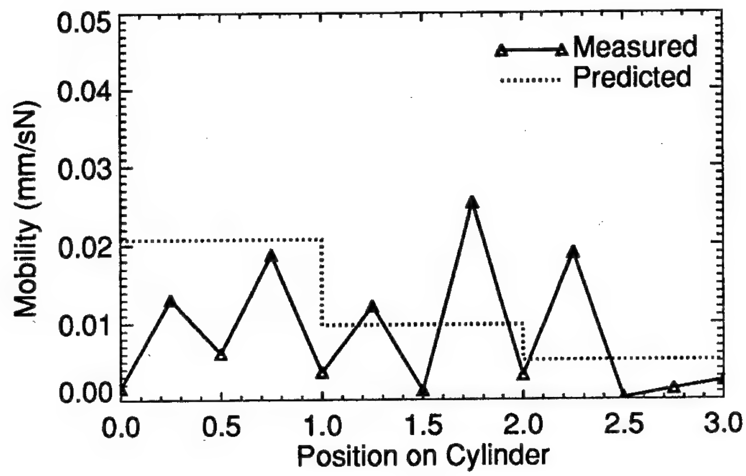

Figure 10: Harmonic Excitation - 5 kHz

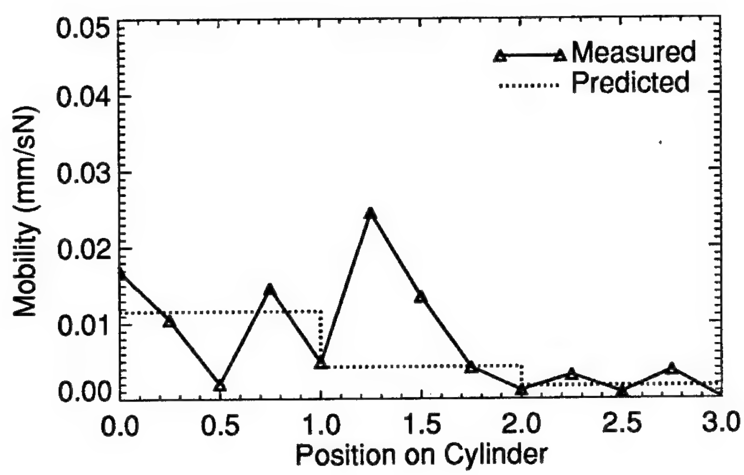

Figure 11: Harmonic Excitation - 10 kHz

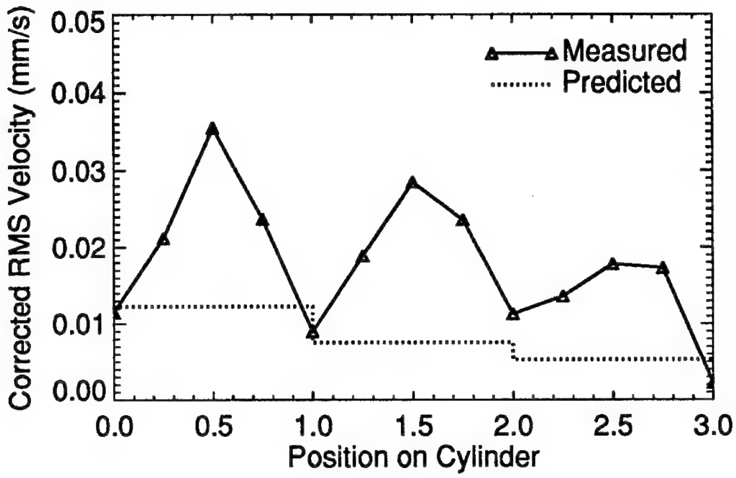

Figure 12: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 2 kHz

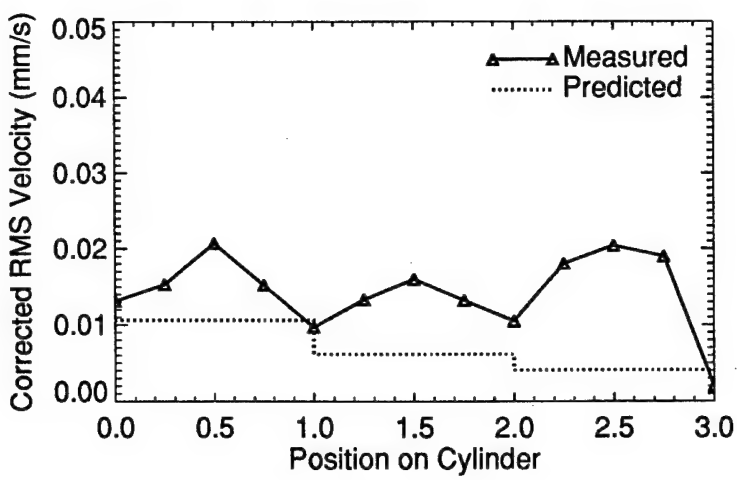

Figure 13: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 2.5 kHz

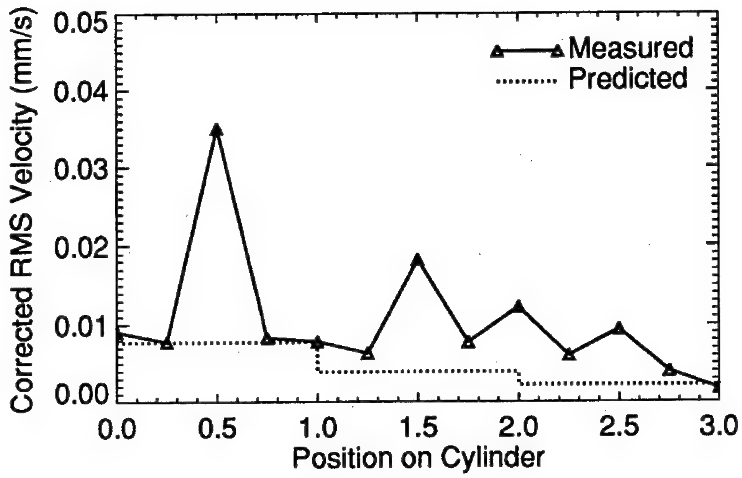

Figure 14: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 4 kHz

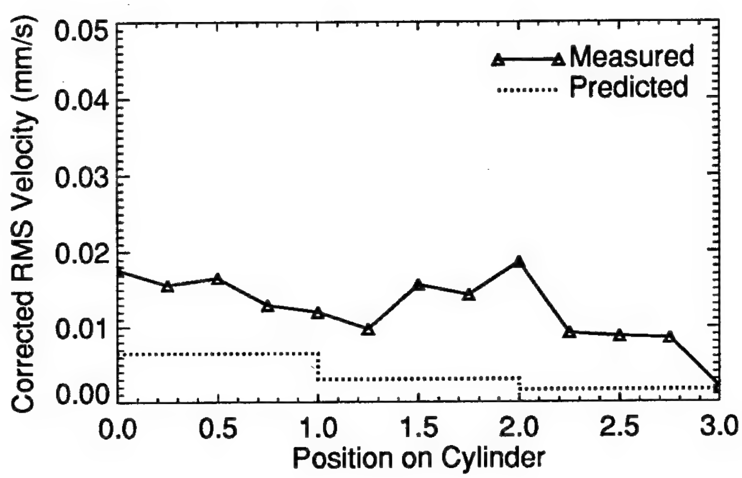

Figure 15: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 5 kHz

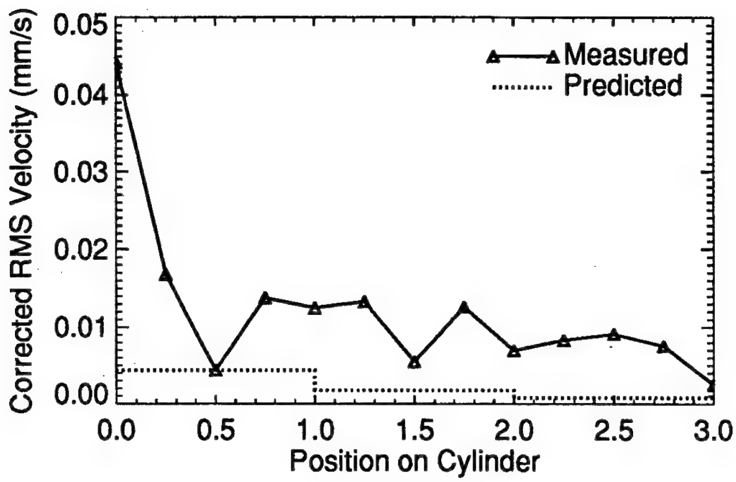

Figure 16: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 8 kHz

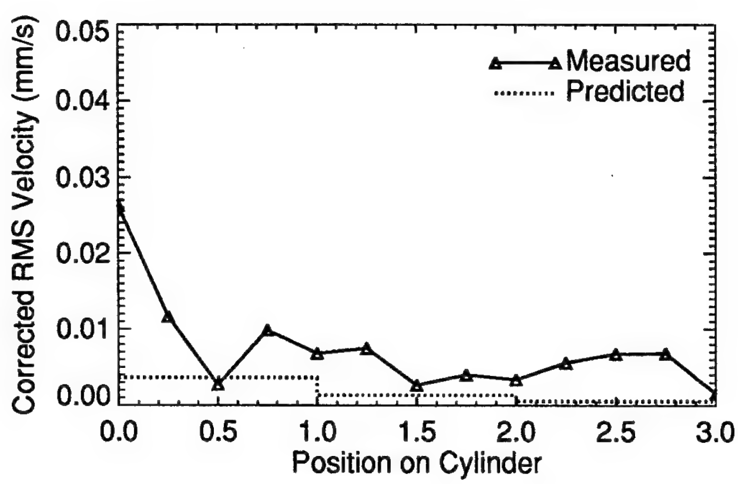

Figure 17: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 10 kHz

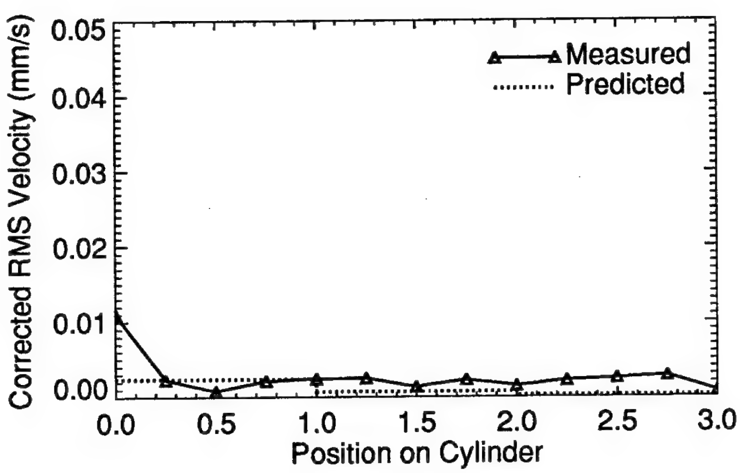

Figure 18: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 16 kHz

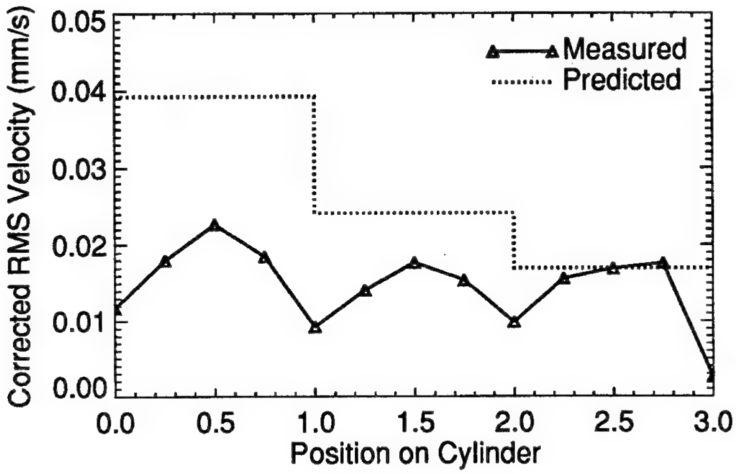

Figure 19: Random Noise Excitation, Full Octave Band Response, Centre Frequency 2 kHz

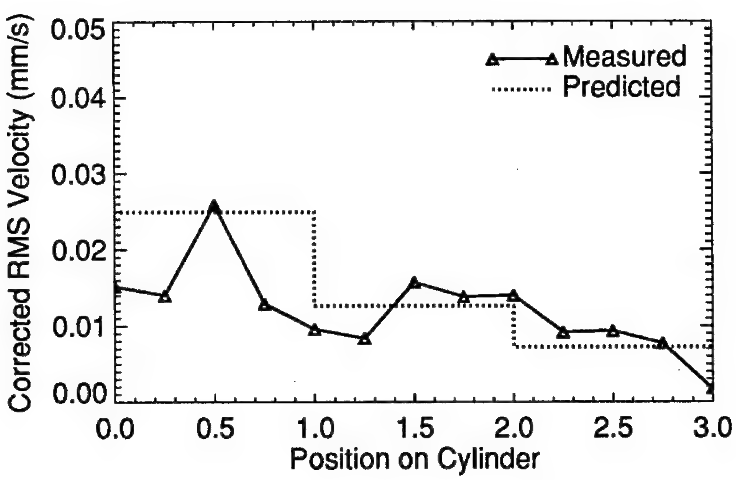

Figure 20: Random Noise Excitation, Full Octave Band Response, Centre Frequency 4 kHz

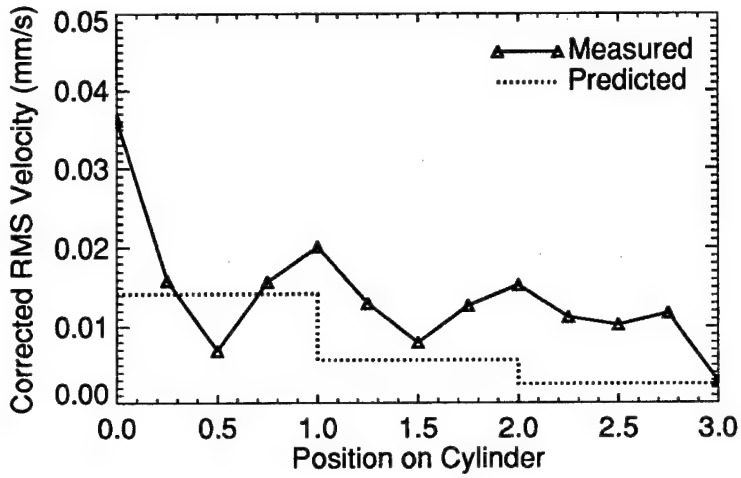

Figure 21: Random Noise Excitation, Full Octave Band Response, Centre Frequency 8 kHz

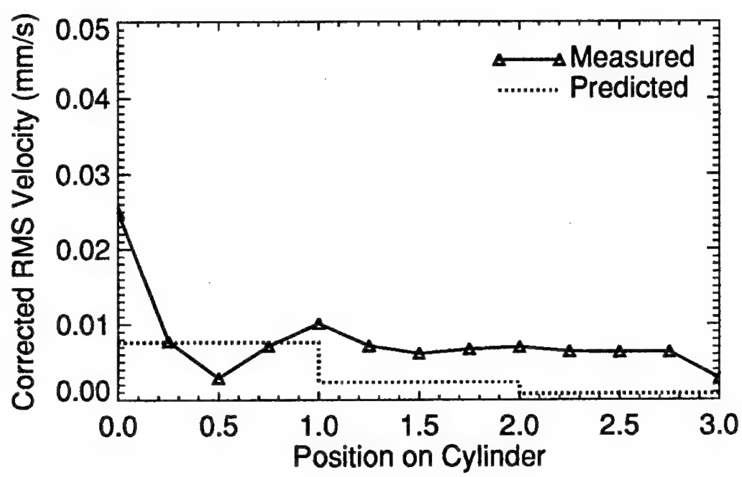

Figure 22: Random Noise Excitation, Full Octave Band Response, Centre Frequency 16 kHz

5.3 Shaker on Shell Plating

With the strong evidence of modal response in the stiffener trials, the harmonic frequencies and octave bands selected for testing with the shaker on the shell were changed. The lower frequencies were dropped and higher values substituted.

5.3.1 Input Power

Figures 23 and 24 show, respectively, the comparison between the measured and predicted input mobility (for the harmonic case) and input power (for the broadband case). Results were actually worse than those with the shaker on the stiffener, with the predicted harmonic input not even of the same magnitude as the measured. The predicted broadband input power compared better with good agreement at 8 and 10 kHz, but relatively poor predictions elsewhere. Again negative input power was measured at some frequencies (see discussion above).

5.3.2 Transfer Mobility

The predicted and measured harmonic response of the cylinder to the shaker placed on the shell are shown in Figures 25 to 30. As can be seen in the figures, the harmonic predictions are quite poor in the lower frequency regime (5 kHz and below), but are more reasonable in the higher frequency domain (8 kHz to 16 kHz). These results do show some modal effects due to the stiffener spacing in the cylinder structure (for this case the stiffener locations were indicated by the -0.5 and +0.5 points on the plot axes).

The results from both the 1/3- and full-octave bands (Figures 31 to 36 and Figures 37 to 40) show excellent agreement between the measured and predicted results. While the power flow method does not predict the actual peak at the input point, the remainder of the responses are in reasonable agreement.

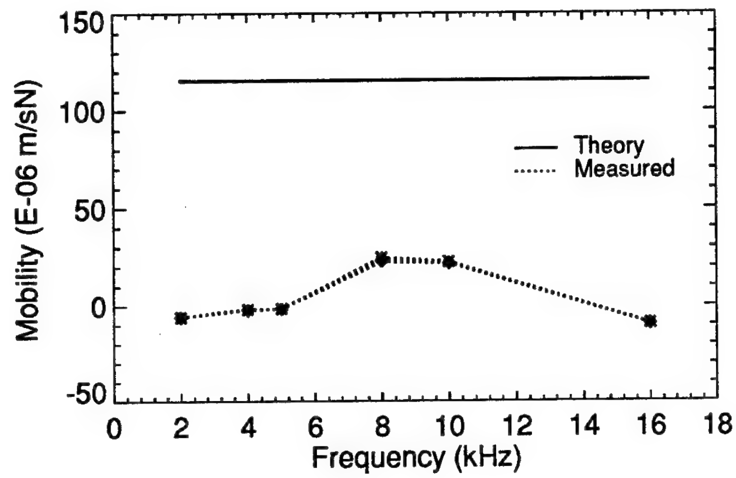

Figure 23: Harmonic Driving Point Mobility (Real Part)

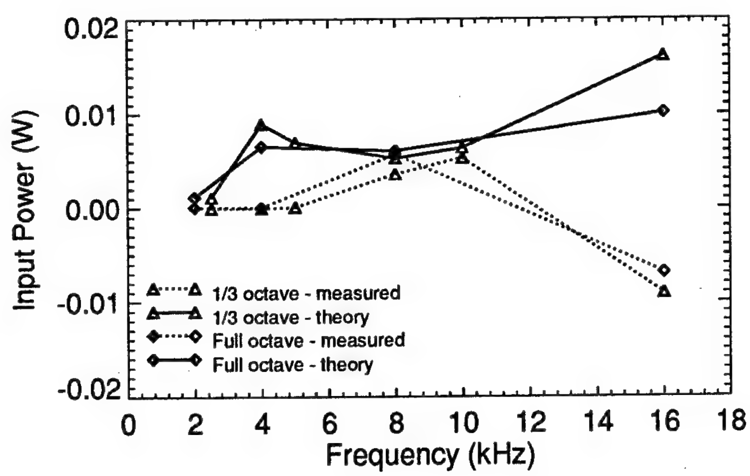

Figure 24: Broadband Input Power

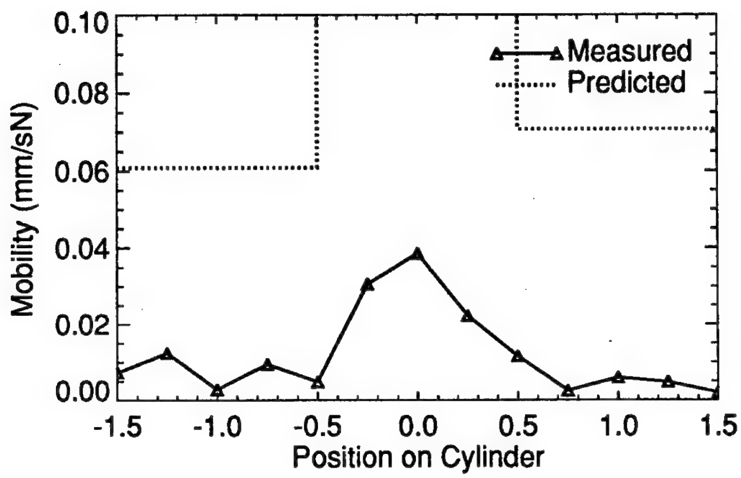

Figure 25: Harmonic Excitation - 2 kHz

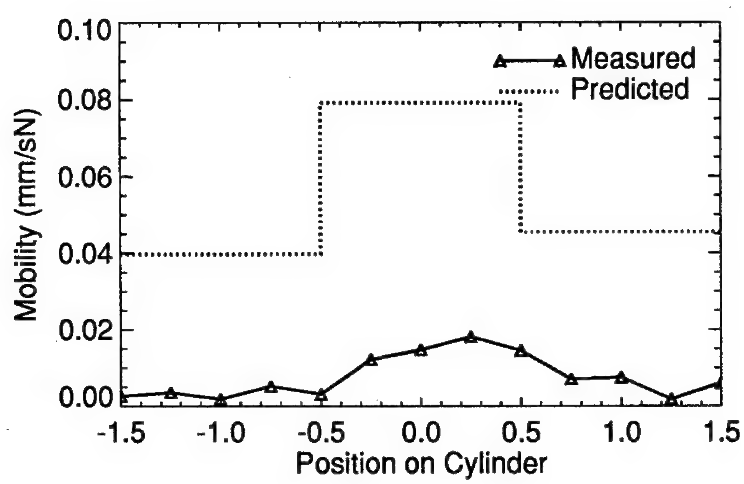

Figure 26: Harmonic Excitation - 4 kHz

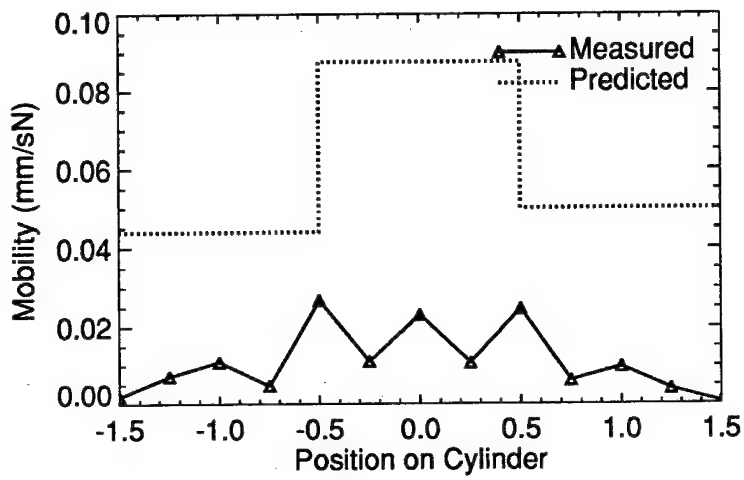

Figure 27: Harmonic Excitation - 5 kHz

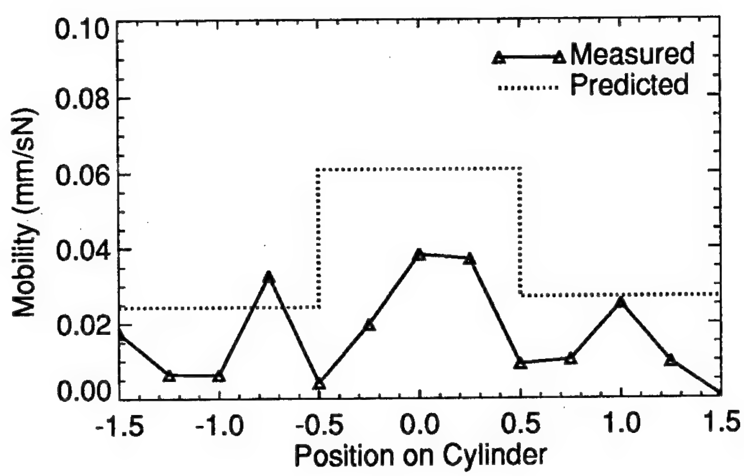

Figure 28: Harmonic Excitation - 8 kHz

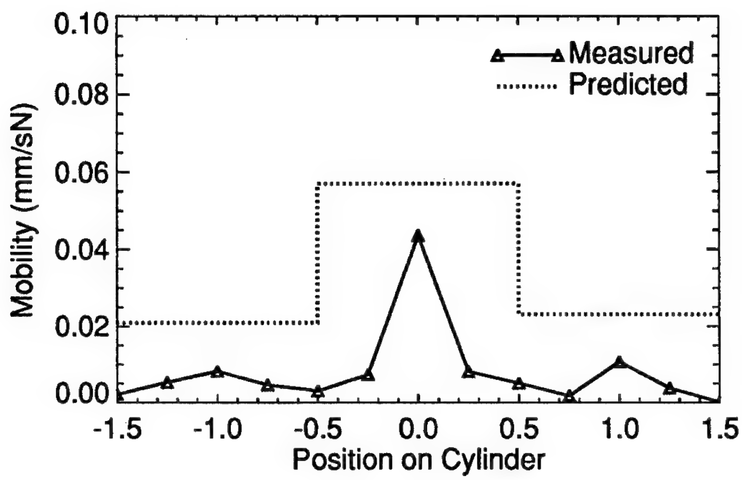

Figure 29: Harmonic Excitation - 10 kHz

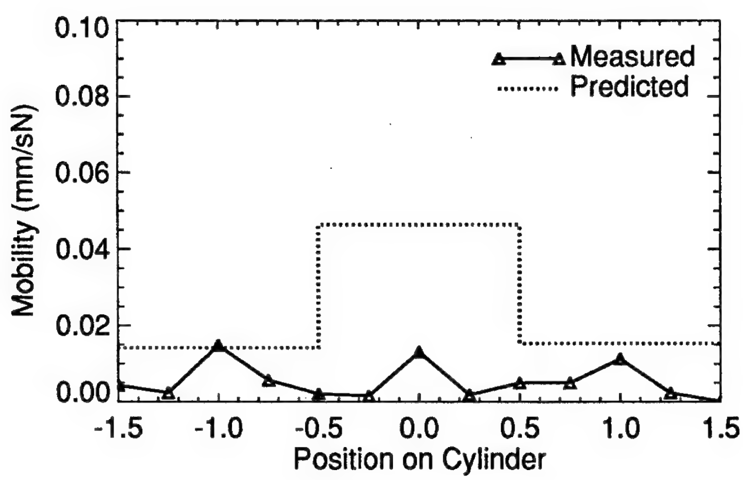

Figure 30: Harmonic Excitation - 16 kHz

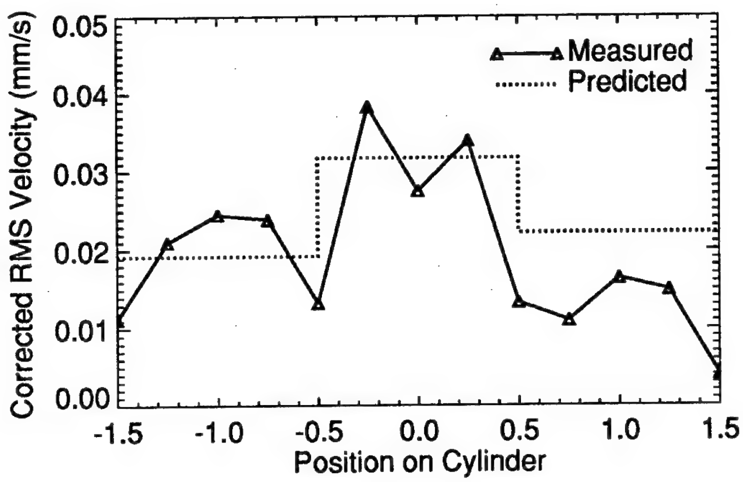

Figure 31: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 2 kHz

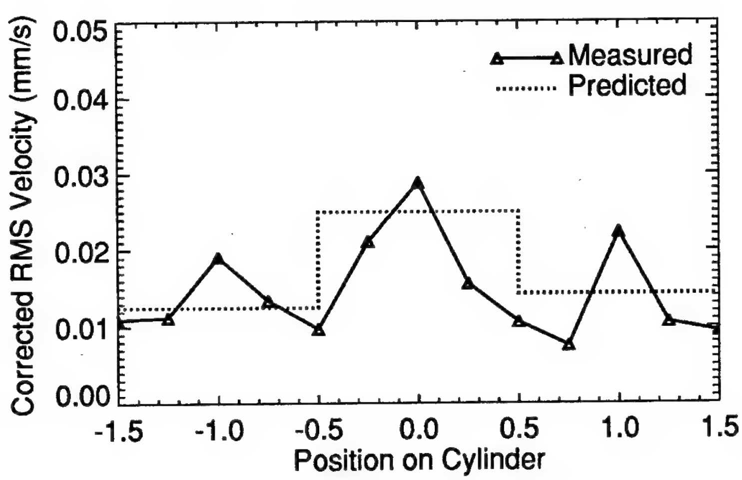

Figure 32: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 4 kHz

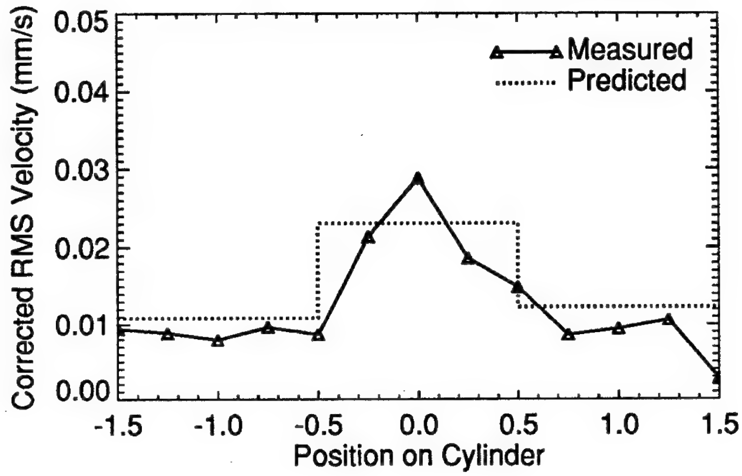

Figure 33: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 5 kHz

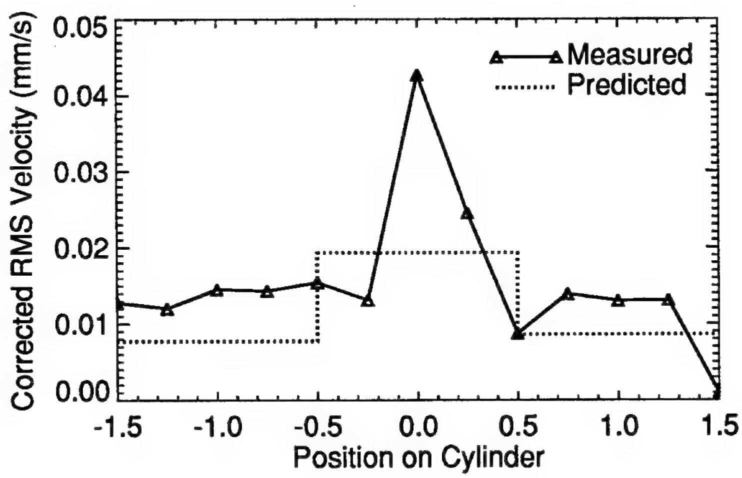

Figure 34: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 8 kHz

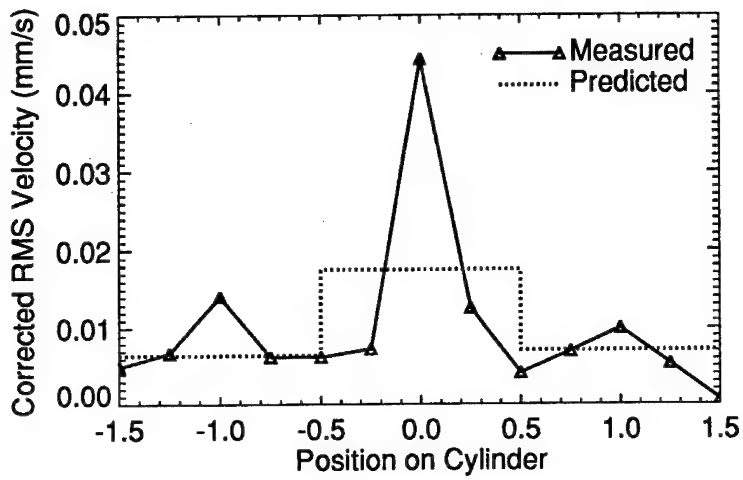

Figure 35: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 10 kHz

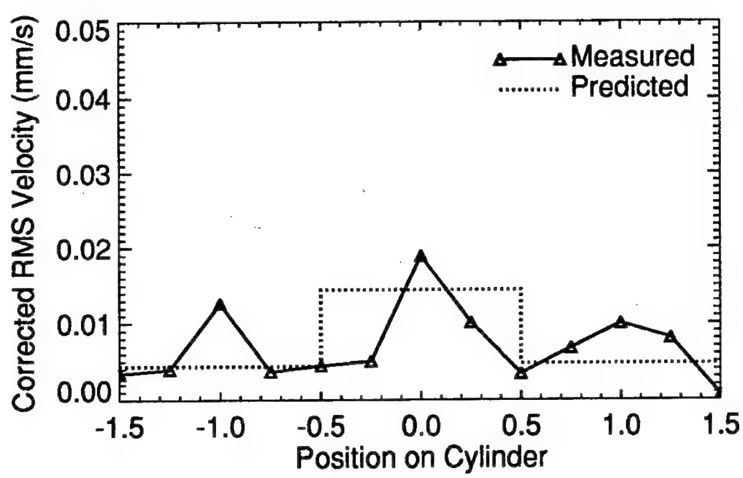

Figure 36: Random Noise Excitation, 1/3 Octave Band Response, Centre Frequency 16 kHz

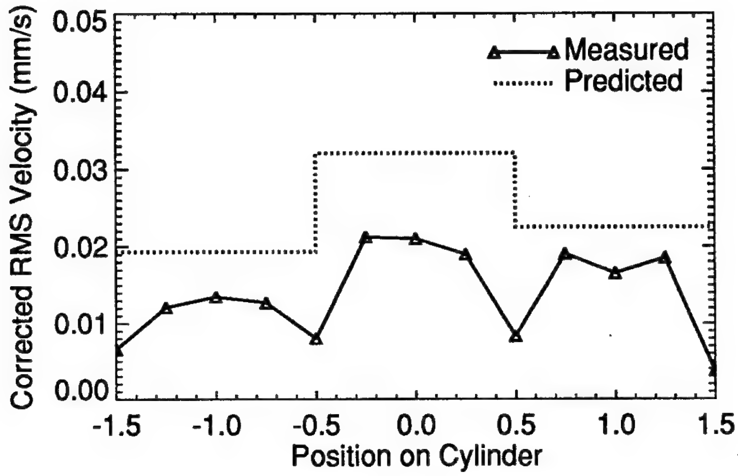

Figure 37: Random Noise Excitation, Full Octave Band Response, Centre Frequency 2 kHz

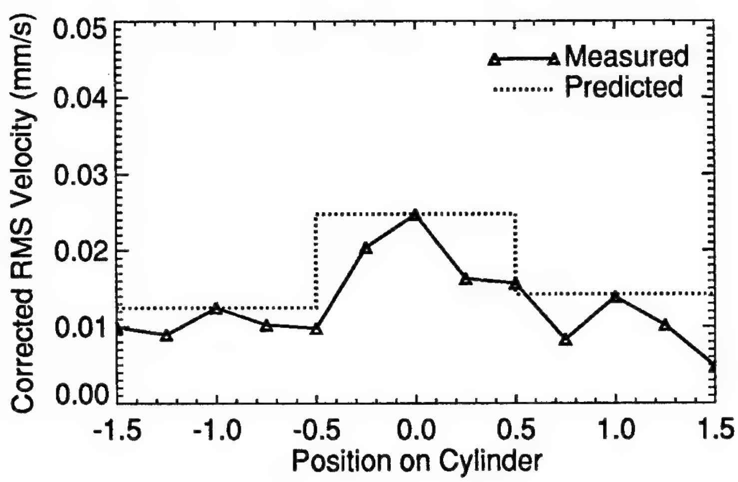

Figure 38: Random Noise Excitation, Full Octave Band Response, Centre Frequency 4 kHz

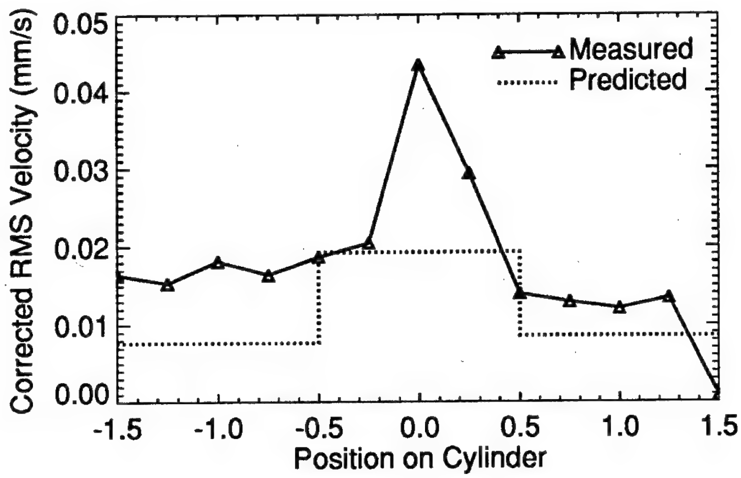

Figure 39: Random Noise Excitation, Full Octave Band Response, Centre Frequency 8 kHz

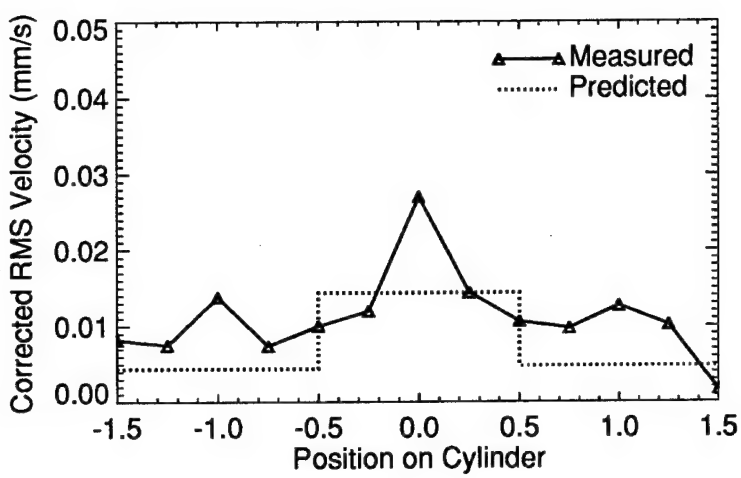

Figure 40: Random Noise Excitation, Full Octave Band Response, Centre Frequency 16 kHz

6 Conclusions

Experiments were performed with DREA's ring-stiffened cylinder to assist in the validation of the PFFEA software for high frequency structural vibrations. The experiments involved excitation of the cylinder structure at relatively high frequencies (2 kHz to 16 kHz, in general) using a combination electromagnetic/piezoelectric shaker located on either the cylinder shell or one of the ring-stiffeners. Both the input power and the vibrational response of the cylinder were measured using an accelerometer with both harmonic and broadband excitation.

The power flow predictions for either input mobility (harmonic case) or input power (broadband case) did not correlate well with the measured data. It was not clear whether this was due to inadequacies in the numerical method or the actual test measurements. The numerical method did not allow for the mass of the shaker (about 3.5kg) and assumed either an infinite plate or an infinite single-stiffened plate. The measured data showed negative input power at some frequencies which may be a result of the shaker and accelerometer not being located exactly opposite to one another or, possibly, a result of radiated noise acting as a secondary source. This radiating noise source could be the reverberant field inside the cylinder or reflection from the walls outside the cylinder. The latter problem may prove difficult to deal with as, no matter what structure is analyzed, it will likely radiate noise which can act as a secondary load path.

In light of these difficulties, the measured forces were used as input to predict the response of the cylinder to both harmonic and broadband excitation. The results from these tests were much more encouraging. The predicted harmonic response did not compare favourably with the measured values, particularly in the frequency ranges dominated by modal behaviour. This behaviour was not unexpected. Predictions were better at the higher frequencies where the response is not modal. The broadband predictions were more accurate for both locations of the shaker for both the 1/3-octave and full-octave band predictions. The 1/3-octave band predictions were more accurate for the shaker on the shell and for both locations the results were better at higher frequencies (outside of the predominantly modal area).

The results from this experiment show that, given the measured input force, the PFFEM can be used to predict the high frequency response of the ring-stiffened cylinder subjected to broadband excitation. Due to its inherent inability to accurately model modal behaviour, the PFFEM cannot be used in frequency ranges were the modal density is relatively low. The PFFEM also appears to be reasonably accurate in its ability to model high frequency harmonic response. The experiments showed that the existing methodology appears to be inadequate in predicting either input mobility or input power or that the experimental procedure needs to be considerably refined to account for the discrepancies. The phenomenon involving the possibility of secondary load paths warrants further investigation to determine if this capability can be included in the software, as this particular class of problems are those likely to be of most interest.

Further testing to validate the PFFEM is required. DREA is currently planning trials involving the measurement of input power and structural response in a compartmented steel

box structure. This will allow for validation of the plate and stiffener junction modelling capabilities of the PFFEM software.

References

[1] Burrell, S.C., Chernuka, M.W., "Extension of Power Flow Finite Element Analysis to Ship Structures - Final Report Part I", Martec Ltd., DREA Contractor Report 91/410, 1990.

[2] Burrell, S.C., Orisamolu, I.R, Chernuka, M.W., "Extension of Power Flow Finite Element Analysis to Ship Structures - Final Report Part II", DREA Contractor Report, CR/93/424, Martec Ltd., 1993.

[3] Burrell, Lieu, Q., S.C., Chernuka, M.W., "Extension of Power Flow Finite Element Analysis to Ship Structures - Final Report Part III", DREA Contractor Report 92/450, 1990.

[4] Smith, M.J., Chernuka, M.W., "Extension of Power Flow Finite Element Analysis to Ship Structures," DREA Contractor Report 96/406, 1996.

[5] Smith, M.J., "Enhancement of Software for PFFEA Modelling and Analysis of Ship Structures," Martec, Ltd., DREA Contractor Report 97/410, 1997.

[6] Smith, M.J., "Advanced Modelling Capabilities for Power Flow Finite Element Analysis (PFFEA)," DREA Contractor Report 97/447, 1997.

[7] Gilroy, L.E., "Mobility Measurements of a Simulated Semi-Infinite Beam Using a Laser Doppler Velocimeter," DREA Technical Memorandum 97/201, 1997.

[8] Gilroy, L.E., "Predicting Radiated Sound from a Submerged Ring-Stiffened Cylinder," DREA Technical Memorandum 96/237, 1997.

[9] Gilroy, L.E., "Comparisons of Numerically Predicted and Experimentally Measured Radiated Noise from a Ring-Stiffened Cylinder," DREA Technical Memorandum 96/217, 1996.

[10] McMahon, G.W., "New Floating Laboratory Facilitates Underwater Acoustic Measurements," Canadian Electronics Engineering, February, 1961.

[11] Liu, S.B., Chernuka, M.W., Smith, M.J., "Transient Heat Transfer Capability for the VASTF Software", DREA Contractor Report CR/95/430, 1995.

[12] "Cylinder," DREA Drawing No. M21-0011.

[13] Linjama, J., Lahti, T., "Measurement of the Bending Wave Power Flow by the Structural Intensity Technique," Espoo 1989, Technical Research Centre of Finland, Research Report 583, 1989.

[14] Skudrzyk, E., "The Mean-Value Method of Predicting the Dynamic Response of Complex Vibrators," JASA, Vol. 67, No. 4, April, 1980.

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Power Flow Finite Element Analysis (PFFEA) has been under development at Defence Research Establishment Atlantic (DREA) in support of the Ship Noise Project. PFFEA is an analysis method for predicting high frequency structural acoustic and vibration response. The method is based on a vibrational conductivity approach in which the flow of vibrational energy is modelled in a similar fashion to heat conduction with convective losses. This report discusses experiments performed with DREA's 3m ring-stiffened cylinder to assist in the validation of the PFFEA software for high frequency structural vibrations. The experiments involved excitation of the cylinder structure at relatively high frequencies using an electromagnetic/piezoelectric shaker located on either the cylinder shell or one of the ring-stiffeners. Both the input power and the response of the cylinder were measured with both harmonic and broadband excitation using an accelerometer. The power flow predictions for either input mobility (harmonic case) or input power (broadband case) did not correlate well with the measured data. The measured applied forces were used as input to predict the response of the cylinder to both harmonic and broadband excitation. Not unexpectedly, the predicted harmonic response did not compare favourably with the measured values in the frequency ranges dominated by modal behaviour; however, predictions were better at the higher frequencies where the response is not modal. The broadband predictions were more accurate for both locations of the shaker. The 1/3-octave band predictions were more accurate for the shaker on the shell and for both locations the results were better at high frequencies.

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